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The removal of volatile organic compounds from supply air using a desiccant column – A theoretical study

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Abstract

The capability of silica gel to remove Volatile Organic Compounds (VOCs) from air under dynamic conditions was theoretically investigated using a packed bed desiccant column. A rigorous model was developed for the prediction of breakthrough profiles of benzene on a silica gel packed desiccant bed. Simulations were carried out on an isothermal, desiccant packed, fixed-bed and single compound-in inert-carrier system to determine the effects of varying operating and design parameters such as bed temperature, initial gas phase concentration, initial adsorbed phase concentration, bed length, particle radius and interstitial velocity. The Dubinin–Raduskevish equation was used to predict the adsorption equilibrium constant, *K*. The characteristic benzene–silica gel breakthrough curves of the adsorption process were produced using Excel. The potential of the model to predict any Adsorbent–VOC breakthrough curves under various operating and design conditions was demonstrated in this paper.

Keywords: VOC; Modelling; Benzene; Silica Gel; Sorption

1. Introduction

Indoor air pollution poses many challenges to the health professionals and the engineers alike. Acute and chronic illnesses emanating from poor indoor air quality in the UK are very common. Studies have shown that people in Europe spend more than 90% of their time indoors and it is this prolonged exposure to air contaminants that is of highest concern (Das et al., 2004). Volatile organic compounds (VOCs) are a class of pollutants that pose a greater risk to human health since they cause toxicity even at very low concentrations (ppb). They include 4–16 carbon alkanes, chlorinated hydrocarbons, alcohols, aldehydes, ketones, esters, terpenes, ethers and aromatics. The adverse health effects caused by these compounds can range from minor complaints such as minor irritations of the nasal and ocular mucosa to chronic complications such as the exacerbation of asthma. Substances such as Benzene which has been linked to cancer in recent studies, are of particular concern to the health of indoor occupants. Benzene is prevalent in outdoor air due to emissions from diesel engines. Removal of VOCs such as benzene by conventional means such as photo catalytic oxidation, air ionisation, condensation and ozone oxidation has proved insufficient due to their existence at very low concentrations.

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Nomenclature

β	affinity coefficient	P	partial pressure of the adsorbate
c	sorbate concentration in fluid phase	P_s	saturated vapour pressure at temp. T
c_o	final ($t \geqslant 0$) steady state value of c (all species)	q	sorbate concentration in the gas phase
C^*	initial concentration of the adsorbate in the adsorbent bed	q_o	final equilibrium value of q
D_L	axial dispersion coefficient	$\bar{q}$	value of q averaged over crystal and pellet
E_o	characteristic adsorption energy for a reference vapour on a specific adsorbent	R_p	adsorbent pellet radius
ε	porosity of adsorbent bed	W_o	maximum amount adsorbed
L	length of spent bed only	R	universal gas constant
L_e	length of bed (both the used and the unused bed) End of bed where exit concentrations are measured	T	temperature in Kelvin
k	overall effective mass transfer coefficient	v	interstitial velocity of fluid
K	dimensionless Henry's law adsorption equilibrium constant	W	amount of the vapour adsorbed on the adsorbent in ml/g
		z	distance measured from column inlet
		φ	dimensionless fluid phase concentration
		τ	dimensionless time variable $\{15D/R^2$ or $k(t - z/v)\}$
		ξ	column length

Most recently the main focus has been on sorption filtration using desiccant materials such as silica gel, zeolites, activated carbons and aluminas for two reasons. Firstly, sorption has been found to be the most effective way of VOC removal. Secondly, the use of desiccants for both dehumidification and pollutant removal (co-sorption) is an energy efficient process because it eliminates the need to cool air to dew point temperatures to remove water vapour. Co-sorption is a process that involves the simultaneous removal of VOC and moisture from supply air. Fang et al. investigated the practical implications of using silica gel packed rotors to determine perceptions of indoor air quality. The results showed a better appreciation of the indoor environment where desiccants had been used (Fang et al., 2005). Even more recently desiccant regeneration techniques involving microwaves have been used and even more energy has been saved this way (Polaert et al., 2010). Several experimental and predictive methods have been used to determine the suitability of the adsorbents for pollutant removal (Das et al., 2004; Elkilani et al., 2003; Huang et al., 2005). However due to the complex nature of the adsorption process many models require prior knowledge of several parameters which rely on experimental data, for example adsorption constants are usually experimentally determined. This paper aims to contribute to the development of a model that can be used to investigate the effects of design, operating and property parameters of any VOC-adsorbent pair. The objectives of this study are:

- To develop a model for the prediction of breakthrough profiles of chosen VOC–adsorbent pairs.
- To use the model to investigate the effects of design, operating and property parameters on adsorption profiles of benzene by silica gel.

2. The adsorption process

Huang et al. (2005) defines adsorption as the separation of a substance from its gas phase and accumulation of the substance in its adsorbed phase on a solid surface. Adsorption also involves the competition for binding sites on the surface of the adsorbent by the adsorbing molecules. Researchers have reported that although this competition also exists between water and pollutant molecules on desiccants, their capacities for pollutant or moisture removal remain relatively unaffected (Lee et al., 2000). A particular adsorption pattern, called the adsorption isotherm defines the relationship between the gas phase and the adsorbed phase concentration at a constant temperature as described in the literature (Das et al., 2004; Huang et al., 2005). Most isotherms take the form of a variant of a sigmoid shape.

However for adsorption of VOCs at low coverage all models tend to transform into a linear model and this is called Henry's Law (Ruthven, 1984). The constant of proportionality (K) is called the Henry constant. The expression for the Henry constant is given as:

$$q = Kc \quad \text{: where } K \text{ can be due to concentration or due to pressure} \tag{1}$$

Henry constants can be used to demonstrate the VOC removal capability of any adsorbent. Desiccant rotor systems can be generally used to "clean up" supply air of VOCs as demonstrated in a typical desiccant based dehumidification system (Fig. 1).

To avoid their accumulation in the conditioned space, room air is pumped to the desiccant rotor where adsorption of VOCs takes place. As recirculated room air passes

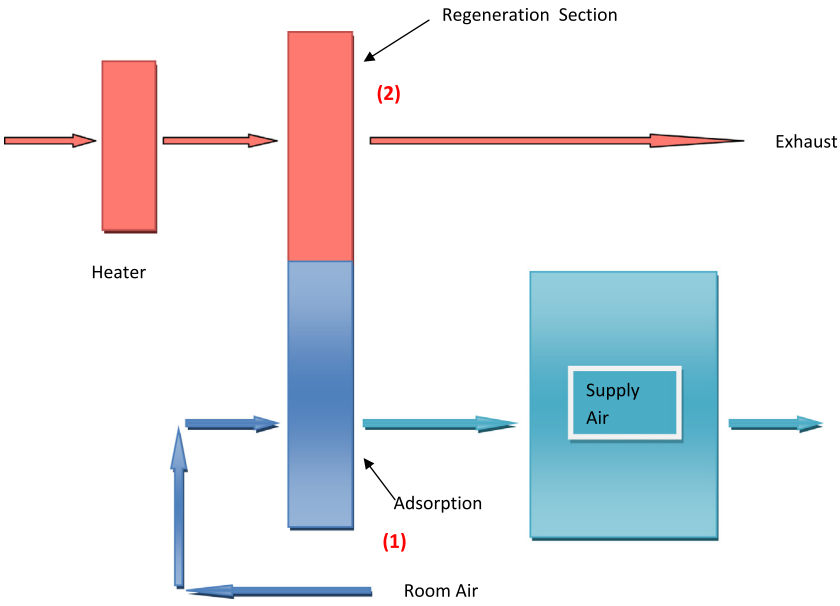

Fig. 1. Typical desiccant based dehumidification system.

through the adsorption section (point 1 on Fig. 1) equilibrium conditions governed by the equation $q = KC$ or $q = Kc$ are generated, depending on the adsorbed phase concentration, and VOCs are removed from the room air. This means the amount of VOC adsorbed on the desiccant will be at equilibrium with the room air gas phase concentration at room temperature. At the regeneration side, relief or outside air heated to a suitable regeneration temperature passes through the desiccant rotor and equilibrium conditions (point 2) are achieved between the outdoor air and the adsorbent. Excess VOCs are expelled this way.

2.1. Developing a mathematical model to predict VOC removal from desiccant columns

In this section, a general mathematical model for the prediction of the time dependent concentration profiles of volatile organic compounds on solid adsorbents under isothermal conditions is developed. Modelling of the response curve must match the experimental response if they are to be used as suitable prediction tools for various solid adsorbents. Theoretical predictions, in principle, determine the dynamic capacity of adsorbent columns or beds without the need for capital and time intensive experimentation. The fixed bed adsorption theory idea to explain VOC removal from desiccant columns. This theory could be further investigated to include applications involving rotating desiccant wheels.

2.2. Fixed bed adsorption theory

The process begins with the idea that in fixed bed adsorption the exiting fluid may be absolutely free of adsorbate until the bed approaches saturation. Generally plug flow systems are characterised by a stoichiometric equilibrium front, the "shock wave", which is a sharp concentration front moving through the bed as shown in Fig. 2. Upstream of the front the adsorbent is saturated with adsorbate and the concentration of solute in the fluid is that of the feed, c_o. The loading of adsorbate on the adsorbent is q_o, in equilibrium with c_o.

The length, or height, of the bed section upstream of the front is identified as $L - 0$ (equilibrium section). In the equilibrium section the adsorbent is spent as expected. Downstream of the front and in the exit fluid, the solute concentration in the flow is zero and the adsorbent is adsorbate-free. The length of the bed section downstream of the front is identified as L_e–L (unused bed). After a period of time, called the *stoichiometric time*, the stoichiometric wave front reaches the end of the bed, the concentration of the solute in the fluid abruptly rises to the inlet value, c_o, no further adsorption is possible, and the adsorption step is terminated. This point is referred to as the *breakpoint* and the stoichiometric wave front becomes the ideal *breakthrough* curve.

2.3. Modelling of isothermal, single transition systems

Starting from an initially sorbate free column or bed (Fig. 2) to either a step change in sorbate concentration at bed/column inlet or to the injection of small pulse at bed/column inlet (step and pulse input, respectively), mass balance and kinetic equations for an element of the adsorption column are derived. For an axially dispersed plug flow the dynamic behaviour at very low concentrations is given by the partial differential equation:

$$-D_L \frac{\partial^2 c}{\partial z^2} + \frac{v\partial(c)}{\partial z} + \frac{\partial c}{\partial t} + \frac{(1-\varepsilon)}{\varepsilon}\frac{\partial \overline{q}}{\partial t} = 0 \qquad (2)$$

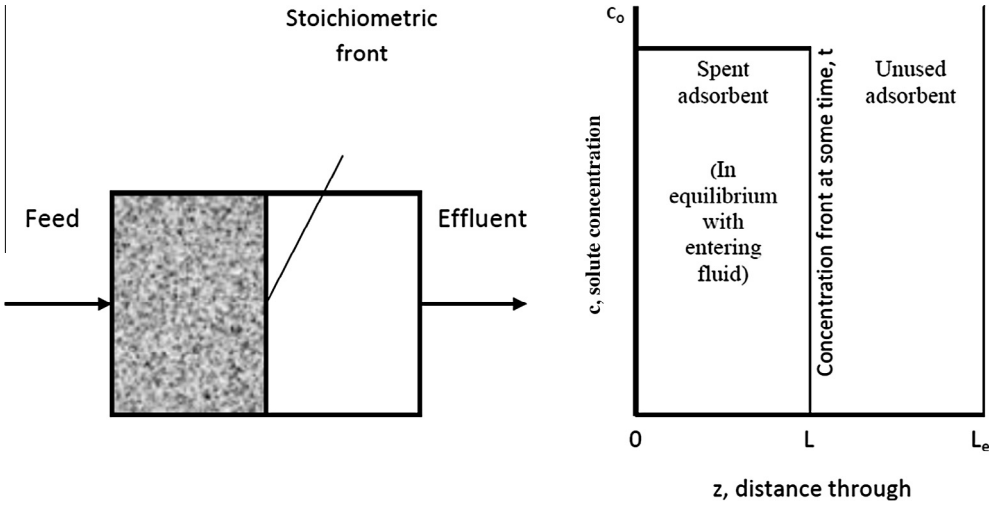

Fig. 2. Stoichiometric (equilibrium) concentration front for an ideal fixed bed adsorption.

The first term accounts for axial dispersion and the D_L component accounts for Eddy diffusion. The next two terms permit an axial variation in fluid velocity and the fourth term is the volume-average adsorbate loading per unit mass (Ruthven, 1984), [30]. The latter term accounts for the variation of q throughout the adsorbent particle, due to internal mass-transfer resistance, by averaging the rate of adsorption over the adsorbent particle. The linear driving force model for mass transfer is given by an expression in Eq. (3), where q^* is the adsorbate loading in equilibrium with the solute concentration, c, in the bulk fluid. Additionally, c' is the concentration in equilibrium with the *average* loading q^-, and k is the overall mass-transfer coefficient, which accounts for both external and internal transport resistances:

$$\frac{\partial \overline{q}}{\partial t} = k(q^* - \overline{q}) = kK(c - c^*) \tag{3}$$

The constant K derives from the equilibrium adsorption isotherm, as Henry's law in this case, $q = Kc$. (Das et al., 2004; Ruthven, 1984; Adsorption notes; Crittenden and John Thomas, 1998)

The fluid mass balance:

$$\frac{\partial \theta}{\partial \xi} + \frac{\partial \psi}{\partial \tau} = 0 \tag{4}$$

Rate Equation:

$$\frac{\partial \psi}{\partial \tau} = \theta - \psi \tag{5}$$

where $\theta = c/c_{o,}$ and $\psi = q^-/q$ and the dimensionless time and bed length parameters are

$$\begin{aligned} \tau &= k\left(t - \tfrac{z}{u}\right) \\ \xi &= \tfrac{kKz}{u}\left(\tfrac{1-\varepsilon_b}{\varepsilon_b}\right) \end{aligned}. \tag{6}$$

Respectively, and k is the overall mass-transfer coefficient, which accounts for both external and internal transport resistances and K is the constant K derived from the equilibrium adsorption isotherm, as Henry's law in this case, $q = Kc$. Final solutions to the differential Eq. (4) and (5), are based on the approximate solution provided by Klinkenberg (Kilkenberg, 1948). Klinkenberg solved the equations based on assumptions of negligible axial dispersion, a constant fluid velocity (u) and correcting the dimensionless time coordinate for displacement. The result of his analytical solution is adopted, as shown in Eq. (10).

$$\frac{c}{c\circ} = q/qo \approx \frac{1}{2}\left[1 + erf\left(\sqrt{\tau} - \sqrt{\xi} - \frac{1}{8\sqrt{\tau}} - \frac{1}{8\sqrt{\xi}}\right)\right] \tag{7}$$

An approximate solution provided by Klinkenberg is accurate to within 0.6% for $x > 2.0$. The function erf(x) ranges from 0.0 at $x = 0$, asymptotically rising to 1.0 for $x > 2.0$; x is a dummy variable. The Klinkenberg solution can also be modified to include the effects of particle radius on breakthrough curves. The overall mass transfer coefficient k, described above can also be written down as $k = 15\ D/R_p^2$ (Ruthven). Therefore it follows that:

$$\xi = \frac{15DKz}{(Rp)^2 * u}\left(\frac{1-\varepsilon_b}{\varepsilon_b}\right) \tag{8}$$

Eq. (7) is only suitable for cases where one begins from an initially sorbate free column or bed to either a step change in sorbate concentration at bed/column inlet or to the injection of small pulse at bed/column inlet. Desiccant wheels are rarely sorbate free unless never used before hence Eq. (7) has been modified to include cases where the initial concentration of the VOC or adsorbate is not equal to zero. A new term c^* is introduced here. To do this, the fact that the maximum value for erf $(X) = +1$ was considered and this happens when the concentration front reaches the end of the bed or column.

$$\text{X is } \left[\left(\sqrt{\tau} - \sqrt{\xi} - \frac{1}{8\sqrt{\tau}} - \frac{1}{8\sqrt{\xi}}\right)\right] \tag{9}$$

Also the minimum value for erf (X) is equal to -1 when the exit concentration c is equal to the initial adsorbed concentration, c^*. In this application a new term (m) was introduced to Eq. (7) such that the exit concentration of the fluid at $t = 0$ (& erf $X = -1$), is equal to the equilibrium concentration between the packed bed and the fluid stream. Similarly the exit concentration at time t (& erf $X = +1$), will be equal to the initial gas phase concentration, c_o. The following general equation was obtained:

$$\frac{c}{c\circ} = \frac{\overline{q}}{q} \approx \frac{1}{m+1}\left[m + erf\left(\sqrt{\tau} - \sqrt{\xi} - \frac{1}{8\sqrt{\tau}} - \frac{1}{8\sqrt{\xi}}\right)\right] \tag{10}$$

Therefore m can be calculated easily if the initial adsorbed phase concentration, c^* is known, or if the concentration of the VOC in the regeneration air stream is known. At $t = 0$, $c = c^*$, therefore solving mathematically:

$$m = \left[\left(\frac{Co + C^*}{Co - C^*}\right)\right] \tag{11}$$

2.4. Modelling desorption

For desorption or regeneration of the adsorbent Eq. (11) applies. Modelling of desorption was not carried out in this exercise.

$$\frac{c}{c\circ} = q/qo \approx \frac{1}{m-1}\left[m - erf\left(\sqrt{\tau} - \sqrt{\xi} - \frac{1}{8\sqrt{\tau}} - \frac{1}{8\sqrt{\xi}}\right)\right] \tag{12}$$

Similarly, Eq. (11) is used to obtain m.

2.5. Adsorption capacity and linear adsorption isotherms

The adsorption capacity is the amount of the molecule adsorbed (the adsorbate) per unit mass of the adsorbent at a given gas-phase concentration under equilibrium conditions. It corresponds to one point on the adsorption isotherm. A number of such models have been proposed for the adsorption isotherm (Huang et al., 2005) and in this case the Dubinin–Raduskevish (DR) Eq. (8); and its modification developed by Stoeckli (Ruthven, 1984) has been used. The DR has will be used to predict isotherms in this study because it has shown a good data fit over a wide concentration range and it is relatively easy to apply. Dubinin postulated that the amount of vapour adsorbed (W) by an activated carbon source, at a relative pressure (P/Ps), is a function of the thermodynamic potential (A), with A expressed as:

$$\mathrm{A} = \mathrm{RT}\ln(\mathrm{Ps/p}) \tag{13}$$

Several tests on organic compounds such as benzene led to the classical expression of Dubinin and Radushkevich (the D–R equation) shown below:

$$\mathrm{W} = \mathrm{W_o}\exp\left[-(A/\beta E_\mathrm{o})^n\right] \tag{14}$$

Benzene is used as a reference compound for carbonaceous materials and its β is assigned the value 1. In order to simulate the adsorption of VOCs on adsorbents, the equilibrium constant, K, was obtained by using the D–R equation. The D-R equation was also used to determine the amount of benzene adsorbed on the silica gel. The saturation pressures of benzene at different temperatures were approximated by using the Claussius–Clapeyron equation (Ruthven, 1984). The Claussius–Clapeyron estimation was applied under the assumptions that: 1, the saturated vapour is an ideal gas; 2, the molar volume of the saturated vapour is much greater than the molar volume of the saturated liquid; and 3, the heat of vapourisation is constant over the temperature range of interest. The pressures selected ensured that the K values for benzene on silica gels were within $\pm 10\%$ of the experimental value. It was also noted that the D–R equation would be also suitable for cases where K values are known, hence its use will only be limited to obtaining corresponding K values at various temperatures for the same VOC–adsorbent pair due to its small range of operating pressure ratios.

3. Results and discussion

3.1. Effect of initial gas phase concentration

Modelling was carried out for varying gas phase concentrations at the inlet whilst keeping all other parameters constant. Inlet concentrations used were typical of indoor conditions and they were 8 μg/m^3, 7 μg/m^3, 6 μg/m^3 and 5 μg/m^3. Simulations were carried out to test the model (Eq. (9)) using a pre-determined adsorption isotherm for benzene on silica gel over a suitable concentration range ($q = Kc$, where $K = 5120$) and an experimentally determined K value from the same experiment (Ruthven, 1984) and the results are described in Fig. 3. The characteristics of the gel and the experimental results are described in Ruthven (1984).

The continual broadening of the wave front in this simulation is typical of that obtained with a linear adsorption isotherm (Lee et al., 2000; Ruthven, 1984). When the isotherm is favourable, such as a Henry isotherm, the wave front broadening diminishes rapidly, leading to an asymptotic or *constant pattern front* (CPF). For such a front, the Mass Transfer Zone (MTZ) becomes almost constant, and the curves of c/c_o and q/q_o become coincident (ASHRAE Handbook, 1991). The curves are in agreement with the above concept. Observed from the results were slight increases in breakthrough times with increases in inlet concentration. Breakthrough concentrations were observed to be around 10 min in each case. The total adsorption time was approximately 120 min for all concentrations although also observed was a slight increase in adsorption time with decrease in concentration.

The slopes of the graphs decrease with a decrease in inlet concentration, also suggesting a delayed total adsorption

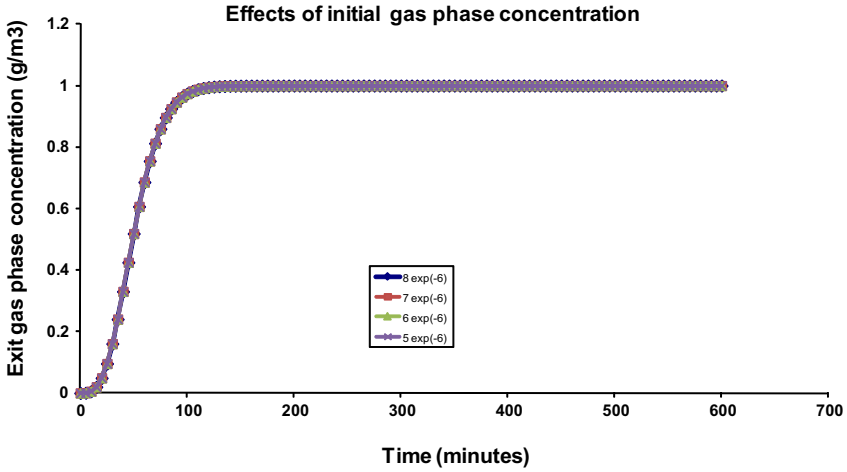

Fig. 3. Effect of initial gas phase concentrations on breakthrough of benzene over 4 × 6 silica gel particles.

time. This can be explained in terms of the amount of VOC entering the pores of silica gel particles under identical mass flow rates. At lower concentrations the saturation of the bed takes longer and consequently adsorption times increase. The results of the model agree with analysis by Das et al. Das et al. (2004) who used a different model to simulate breakthrough curves of toluene on activated carbon fibres. Total adsorption times are well into the range that may facilitate the use of silica gels in desiccant columns and the results clearly indicate the potential of silica gel particles for use as a benzene adsorbent.

Table 1
Gas phase concentrations and corresponding adsorbed phase concentrations for silica gel at 294 K.

Gas phase concentration (g/m^3)	Adsorbed phase concentration (g/m^3)
5 exp (−6)	0.026
6 exp (−6)	0.031
7 exp (−6)	0.036

3.2. Effects of initial adsorbed phase concentration

The effect of the concentration of the VOC in the silica gel micro pores on the adsorption process was studied by varying the concentration of benzene in the adsorbed phase. The concentration range chosen lies between typical indoor and outdoor benzene concentrations, since the use of outside air as regeneration air during an adsorption cycle is a cheap alternative. It is also highly unlikely that regeneration will remove all VOCs from the desiccant wheel because the process depends on equilibrium conditions which are rarely achieved in practise. Adsorbed phase concentrations and their corresponding gas phase concentrations are shown in Table 1.

The breakthrough curves in Fig. 4 shows no significant changes in total adsorption time as adsorbed phase concentration increases or decreases. Explaining the slight increase in breakthrough time as the adsorbed phase concentration increases is less important. It can deduced however from the reduction in the slope of the breakthrough curve as the adsorbed phase concentration increases that

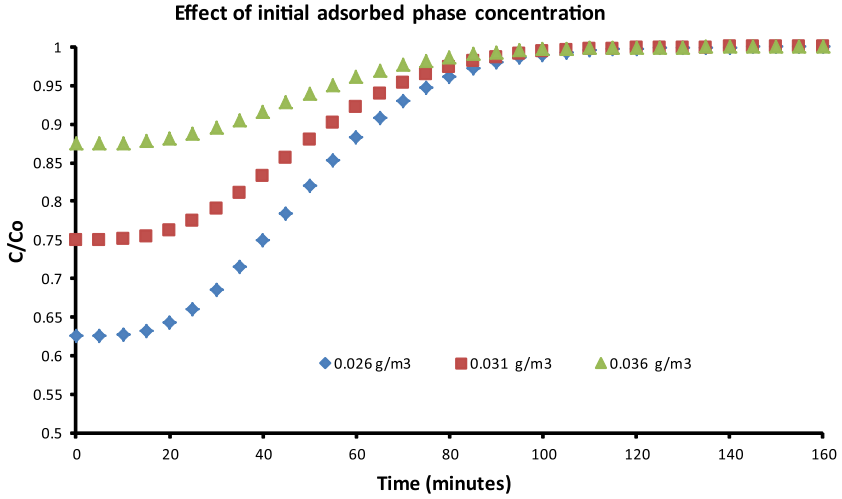

Fig. 4. Effect of initial adsorbed phase concentration on benzene removal by 4 × 6 mesh silica gel particles.

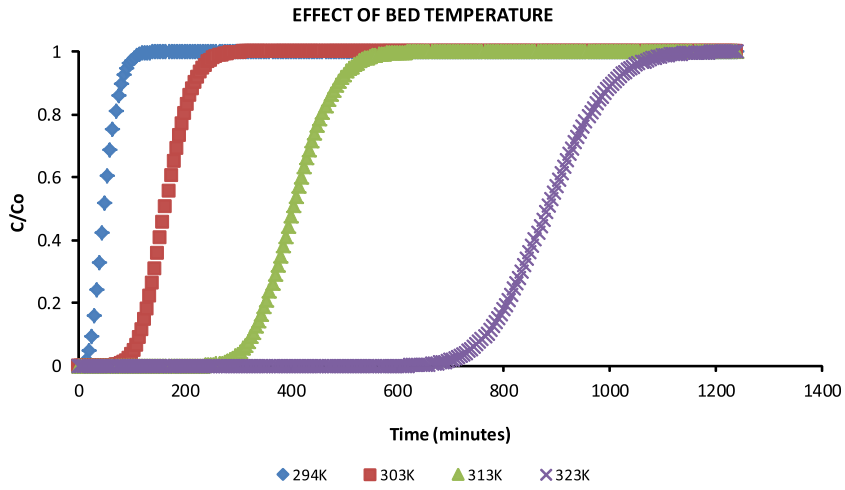

Fig. 5. Effect of bed temperature on the adsorption characteristics of benzene on silica gel.

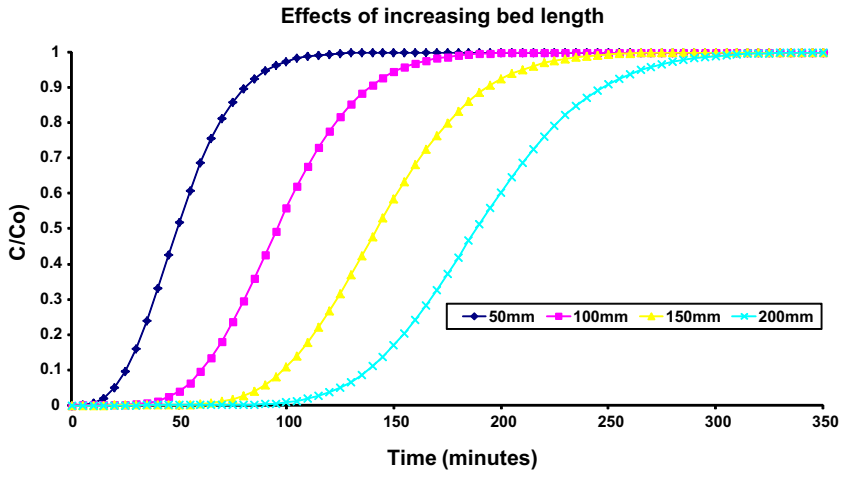

Fig. 6. Effect of bed length on breakthrough of benzene over silica gel particles.

at a higher adsorbed phase concentration VOC removal is less.

3.3. Effect of bed temperature (K)

Simulations were carried out between the temperatures 294 K and 323 K whilst other parameters remained constant. The breakthrough times and total adsorption times were found to decrease slightly with a decrease in temperature as shown in Fig. 5. The breakthrough curve also shifts to the left as the temperature of the bed is increased. Faster breakthrough and desorption time can be explained by the fact that at higher temperatures three mechanisms control adsorption namely (1) diffusion from the bulk phase to the adsorbent surface, (2) migration into pores of the silica gel particles and (3) monolayer build up and destruction of benzene happening faster.

Since effective diffusivities are a function of temperature, higher temperatures mean K values are lower and therefore saturation happens more quickly. The temperature dependence of K further confirms the need for higher temperatures during regeneration.

3.4. Increasing/decreasing bed length

Whilst keeping other parameters constant, simulation was carried out at the following bed lengths: 50 mm, 100 mm, 150 mm and 200 mm. As seen in Fig. 6, increasing the bed length increased both breakthrough time and total adsorption time linearly. The slopes of the breakthrough curves also reduced slightly with increases in bed length. The model shows good agreement with the concept of a moving concentration front. It takes the concentration front a longer time to cover a longer distance than a shorter distance.

The model results are consistent with the fact that it takes longer for the concentration wave front to travel long distances as compared to shorter ones. Both the breakthrough times and total adsorption times increase linearly with the increase in bed length although the rate of increase

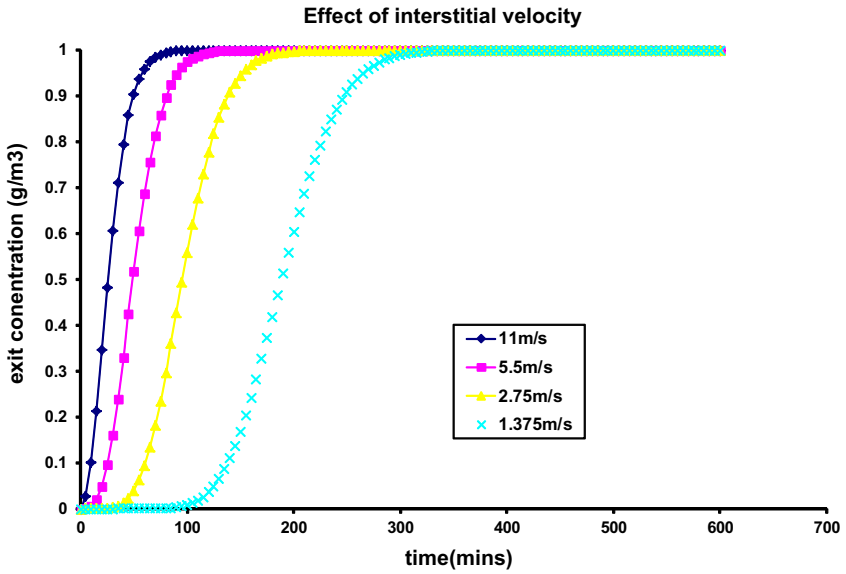

Fig. 7. Effect of changing the interstitial velocity on breakthrough profiles of benzene on silica gel.

of total adsorption time is higher than the rate at which the break through times increase with increase in bed length. The slopes of the curves towards asymptotes also suggest this.

3.5. Effect of changing interstitial velocity

Since mass flow rates depend on the cross sectional area of the inlet (radius of section) this parameter was kept at 5 mm during the simulation. The mass flow rates applied were 54, 27, 13.5 and 6.74 kg per minute and Fig. 7 shows the results. Interstitial velocity changes had large effects on the breakthrough profiles. For example doubling the mass flow rate from 6.74 (interstitial velocity = 1.375) to 13.5 (interstitial velocity = 2.75) kg per minute resulted in an increase in the breakthrough time from about 50 to around 100 min.

As explained earlier the reason for observed early breakthroughs as mass flow rates were increased may be due to the increased amount of material entering the bed. Early saturation of the bed at higher interstitial velocity may be due to the same effects although it is difficult to ascertain this. At lower mass flow rates the model shows an early breakthrough followed by delayed saturation whilst at higher mass flow rates an early breakthrough and an early saturation is observed. This is clearly evident from the slopes of the curves.

3.6. Effects of particle diameter

The use of $15D/Rp^2$ to calculate k is common since it works well for linear systems i.e. low loadings and k has effects on axial dispersion and mass transfer resistance (Crittenden and John Thomas, 1998). From this study it

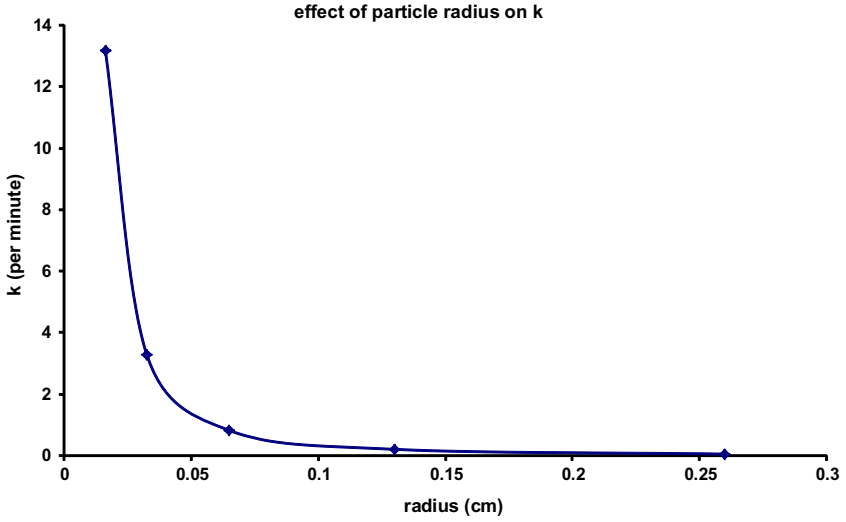

Fig. 8. Effect of particle radius on the overall effective mass-transfer resistance (k).

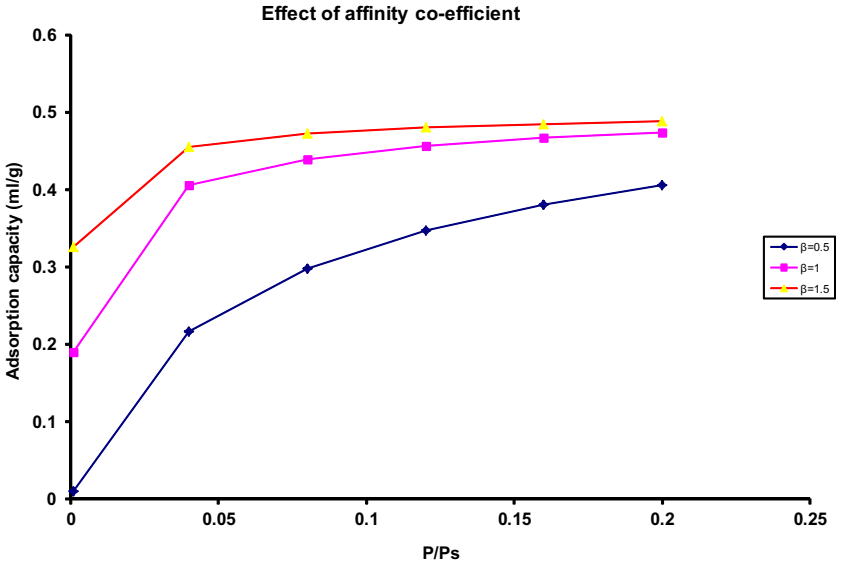

Fig. 9. Effect of affinity coefficient on adsorption capacity of adsorbent.

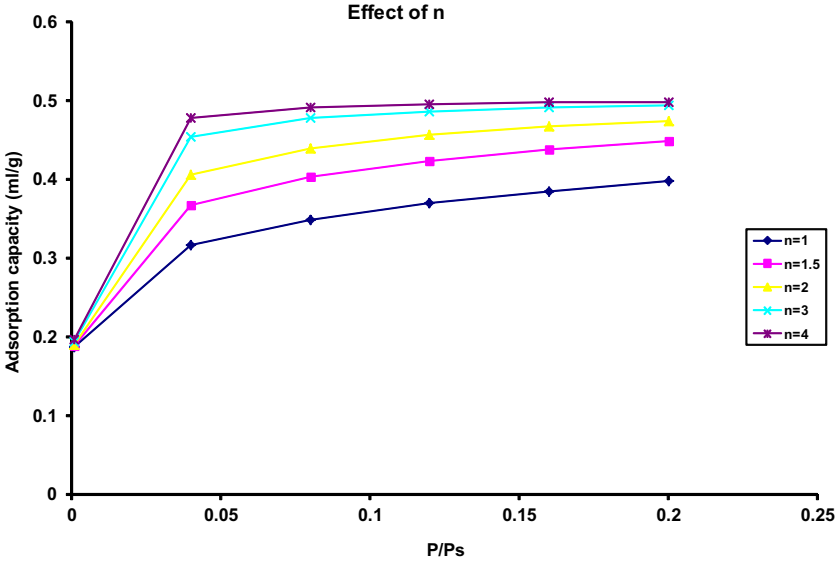

Fig. 10. Effect of n on the adsorption capacity of an adsorbent.

was observed that as the particle radius increases k approaches zero and the effects are also evident on the breakthrough curve as shown in Fig. 8.

3.7. Desorption and regeneration

A good quality adsorbent should be able to remove VOCs from the indoor air and thereafter regenerate sufficiently to be able to effectively operate during subsequent cycles. Our model was again used to simulate desorption of benzene in silica gel. During the investigation of the effect of temperature on the adsorption of benzene it was noted with interest the poor performance of the adsorbent at higher temperatures. A regeneration temperature of 353 K was used for the simulation of regeneration. This temperature was increased to 373 K, and as with other simulations above other parameters remained constant. Using the corresponding K value and simulation for both temperatures at typical UK outdoor air containing 5 exp (−6) g/m3 benzene, curves that were direct opposite of what would have been adsorption curves, were observed.

3.8. The effect of index (n) on the adsorption capacity at various pressure ratios

The effects of the index n on the adsorption capacity of adsorbents were investigated. The parameter n is temperature invariant and it is part of the adsorption isotherm (Artur et al., 2002). It is also a material property hence its effects at various pressures and the results are displayed

in Fig. 9 were investigated. The plot also shows a significant impact of n at low relative pressures. This may also be linked to failures by the D–R equation at low relative pressures.

3.9. The effect of index (n) on the adsorption capacity at various pressure ratios

The effects of the index n on the adsorption capacity of adsorbents were also investigated. The parameter n is a temperature invariant and it is part of the adsorption isotherm (Artur et al., 2002). It is also a material property hence its effects at various pressures were investigated and the results are displayed in Fig. 10. The plot also shows a significant impact of n at low relative pressures. This may also be linked to failures by the D–R equation at low relative pressures.

4. Conclusions

Simulation results revealed silica gel packed rotating columns are capable of removing VOCs from indoor air. The study also reveals the effectiveness of silica gels in removing benzene from indoor air. The mathematical model proved to be a good tool for predicting the effect of various parameters affecting adsorption of VOCs from indoor air. The D–R equation has been found to be a reliable predictor of equilibrium constant, K, for any VOC–adsorbent combination at certain pressure ratios. The correction factor's (β) sensitivity to pressure ratios has been found to be the main reason why the D–R equation has limited flexibility in predicting VOC adsorption capacity. This approach could be used to predict VOC removal in desiccant based air conditioning systems.

Future work

Further research needs to be carried out in order to apply the principles discussed to rotary wheels.

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